SEISMIC CHARACTERIZATION OF A GLACIATED MULTI-LAYERED AQUIFER SYSTEM IN CENTRAL ILLINOIS.

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Abstract:

High-resolution compressional (P)-wave seismic reflection profiles were conducted over the Mahomet Bedrock Valley in central Illinois to determine the lateral and vertical distribution of the aquifer units comprising the Mahomet Aquifer System and locate areas of interconnection between the various aquifer units. The Mahomet aquifer units comprises several deposits that forms a complex hydrogeological setting, which is difficult to characterize with traditional electrical and electromagnetic geophysical methods. In the study area, the Mahomet Aquifer lies approximately 80 m below ground surface beneath a thick succession of glacial and non-glacial deposits. The aquifer is situated over the MBV, which has no surface expression. P-wave seismic data used in this study was acquired along five separate transects, totaling,~13 kilometers using the seismic land streamer technology. Processing the data was complicated by strong coherent noise, such as guided and surface waves. Interpreting the processed seismic profiles into lithological units was constrained by lithological descriptions and geophysical logs (gamma, Vp, and Vs) from boreholes along and within the vicinity of the seismic profiles. The seismic interpretation showed three continuous units within the Mahomet Aquifer System. These units include; (1) the regionally extensive Mahomet aquifer containing a lower unit composed mainly of well sorted coarse sand and gravel overlain by fine sand, upper unit, (2) coarse-grained deposits of the Pearl Formation (lower Glasford Aquifer) comprised mainly of moderately to poorly sorted fine sand to gravel, and (3) a thin discontinuous layer of sand and gravel (upper Glasford Aquifer) at the base of the upper unit of the Vandalia Member. Areas of deteriorated seismic signals are interpreted as windows of interconnection between the Mahomet aquifer and the overlying aquifers. Given the inherent complexities in the subsurface and the depth to the Mahomet aquifer, acquisition of high resolution P-wave seismic reflection data is considered effective in resolving the thin aquifer units.

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CHAPTER I

INTRODUCTION

Illinois was glaciated by continental glacial of the south-central margin of the Laurentide Ice Sheet during the Quaternary, Curry et al. (2011), leaving deposits of at least three glacial episodes Wisconsin (WI), Illinois (IL) and pre-Illinois (PIL). Each glacial episode included several advances and retreats, then proceeded by an interglacial period in which the climate warmed and the ice front melted back (Selkregg and Kempton, 1958) . The glacial drift deposited by the major glacial advances and retreats host relatively thick sand and gravel aquifers and the underlain indurated bedrock valleys also contain extensive sand and gravel aquifers such as the Mahomet Aquifer. In central Illinois, (Fig. 1.1), the over one ½ million residents rely on the Mahomet Aquifer System for their drinking water and water used for most other purposes: domestic, industrial, agriculture and commercial. The United States Environmental Protection agency designated the Mahomet Aquifer System as a “sole source” aquifer (implying that the aquifer system supplies at least 50% of drinking water to the region and there are no reasonably available alternative drinking water sources should the aquifer become contaminated). The aquifer system includes the Mahomet aquifer, which is overlain by thin and discontinuous aquifer units, partially within the boundary of the buried Mahomet Bedrock Valley (Fig. 2.1).

Within this system, the Mahomet Aquifer is the largest and most important aquifer unit and represents the primary water resource to most communities in central Illinois. The Mahomet Aquifer System is composed of glacial drift aquifer comprised of glaciofluvial or glacial outwash deposits. The deposits forming the aquifer system are characterized by their heterogeneity and resultant numerous lithologic discontinuities (Stephenson et al., 1988), facies variability, variable geophysical properties, sedimentological complexity and stratigraphic heterogeneity (Boyce and Eyles, 2000). The heterogeneity encountered in many glacial drift aquifers is the single most important factor affecting the hydrogeologic characteristics (Stephenson et al., 1988). The variability in facies results from a complex history of glacial and postglacial events (Atkinson et al., 2014).

Stephenson et al. (1988) noted that a complete understanding of glacial processes is necessary to interpret the hydrogeology of glaciated terrain. In addition, largest-scale features of the Mahomet Aquifer System are deeply buried by thick aquitard units formed during subsequent glaciations, and have no surface expression. An exception is the western part of the aquifer system where the Mahomet aquifer is in direct connection with the surface hydrologic system because several different glaciofluvial deposits overlap each another (Roadcap et al., 2011; Stumpf and Ismail, 2013), thus cannot be mapped from surficial geologic data. , Furthermore, the extent and thickness of the Mahomet aquifer is even more variable than previously thought, because recent studies have determined the bedrock surface has numerous undulations and isolated structurally-controlled protrusions, which together reduce the aquifer thickness (Herzog et al., 1995; Mehnert et al., 2004).

Complexities in the glacial sequence make an extremely challenging geologic setting to characterize using geophysical methods. Geophysical methods can play a role in proper imaging and accurate characterization of glacial aquifers when correctly applied. Amongst the various geophysical techniques (electric/electromagnetic, ground penetrating radar and seismic methods) suitable for imaging the near subsurface, high-resolution seismic reflection (HRSR) surveys have been the primary method used in glaciated terrain of the Northern Hemisphere (BURVAL Working Group, 2009), including Illinois (Stumpf and Ismail, 2013). Francese et al. (2007) cited the NSERC Dalmeny example where standard, borehole-based geological exploration could not successfully locate the aquifers in channel deposits targeted for a supply water. These aquifers are commonly isolated or discontinuous.

To successfully delineate the aquifers comprising the Mahomet Aquifer System, we utilized high-resolution seismic reflection P-wave. This method is more suitable for groundwater exploration because it can be used to characterize deposits having different porosity, density, clay content and degree of saturation. Unlike the S-wave seismic method, which is less sensitive to changes in moisture content (Ismail et al., 2014), Mavko and Nur (1979) and Korneev et al. (2004) have proven experimentally that the amplitude of P-waves travelling through water-saturated materials normally are higher than P-waves amplitude travelling through unsaturated deposits. Despite the formidable challenges posed by glacial sedimentary environments, numerous authors have found success in the characterization of such deposits. FRANCESE et al. (2007) used high resolution seismic reflection to successfully locate the potential production zones of aquifers embedded in channel deposits targeted to supply water to a major urban settlement, standard borehole based, geological exploration could not because of their small scale and the lateral discontinuity of the structures. Bradford et al. (1998) also used seismic reflection profiles to image a shallow (<100 m) aquifer system in temperate glacial sediments at Puget Sound, Seattle. Giustiniani et al. (2008) characterized an important multilayered aquifer located in the Friuli-Venezia Giulia plain (NE of Italy) using high-resolution seismic data.

In this study, five high-resolution seismic reflection profiles were acquired in the summer of 2007 across the Mahomet Bedrock Valley to determine the lateral and vertical distributions of aquifer units comprising the Mahomet Aquifer System and the glacial and non-glacial sediments that infill the Mahomet Bedrock Valley. A second objective was to find areas where the aquifer units may be hydrologically connected. The study area in rural western Champaign County (Fig. 1.1) was chosen to benefit from an array of downhole geophysical and geological logs acquired by Illinois State Geological Survey to study the Mahomet aquifer and provide stakeholders of the aquifer important information for managing groundwater extraction in the future. Our results show that the P-wave penetrating depth using a 36-geophones spaced at 2 m intervals and a 50 lb. weight drop was sufficient to image the aquifer and underlying bedrock surface and provide an accurate spatial representation of hydrogeologic units.

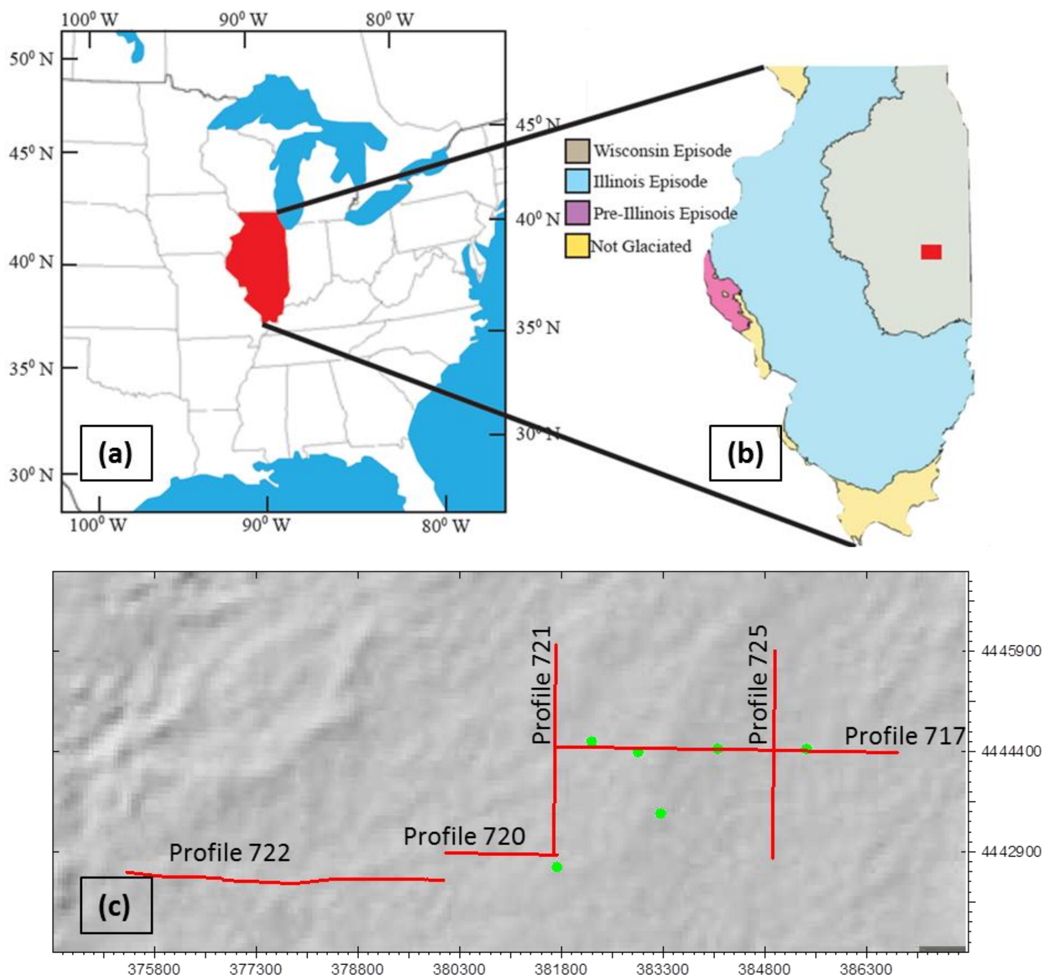

Figure 1. 1. A location map showing the location of Illinois in United States (a), the glacial map of Illinois (b) and the study area with the seismic survey layout (C).

CHAPTER II

GEOLOGIC SETTING AND SITE DESCRIPTION

The present-day landscape of Illinois is remarkably different from prior topographies having been severely impacted by glacial and its associated meltwater to different degrees. During the Pleistocene Epoch, glaciers flowed across the study area during at least three different episodes. For example during the pre-Illinois episode, the surface landscape was characterized by rolling to gently undulating uplands that were dissected by an integrated system of valleys deeply incised into the bedrock (Stumpf and Dey 2012). Whereas the modern landscape is low-relief and includes a series of curvilinear end moraines.

In central Illinois, the most prominent feature on the bedrock surface is the deeply incised valley, the Mahomet Bedrock Valley and tributary valleys (Fig. 2.1). The bedrock valley formed part of an expansive preglacial bedrock drainage network, the Teays-Mahomet Bedrock Valley System, which contained a river with headwaters in the western Appalachian Mountains (Kempton et al. 1992). In the major valleys such as the Mackinaw and Mahomet Bedrock Valleys, meltwater flowing away from ice margins carried enormous amount of coarse-grained sediments (sand and gravel) down valleys, while in the tributaries, the meltwater was ponded, (Stumpf and Ismail, 2013)

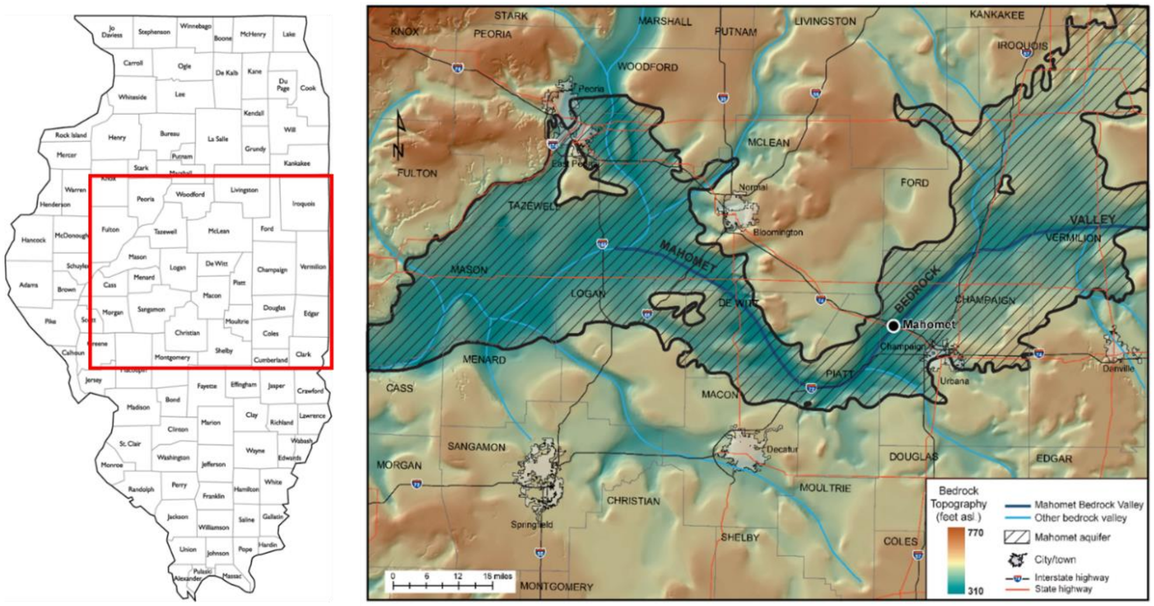

Figure 2.1. The Mahomet Bedrock Valley (courtesy of the Illinois State Geological Survey)

Below the Wisconsin Episode deposits (mostly glacial till or diamicton) that comprise the upper 30 m of the glacial sequence above Illinois and pre-Illinois Episodes deposits, specifically of the Glasford, Pearl, and Banner Formations. The Glasford Formation includes an upper interstratified deposit containing diamicton, silt and clay, and sand and gravel. In the central part of the study area, a similar deposit infills a tributary of a larger glacial valley system eroded into the underlying unconsolidated sediment (Stumpf and Dey, 2012). The interstratified deposit overlies a loam-textured diamicton (Vandalia Member). The lower part of the Glasford Formation is comprised of sand and gravel deposited as outwash terrace, plains or valley trains in front of advancing Vandalia glaciers. The sand and gravel ranges from 20–60 feet thick and often directly overlies sand and gravel (Mahomet Sand Member) of the Banner Formation. Sand and gravel classified to the Mahomet Sand Member was deposited as glacial outwash that almost entirely fills the Mahomet Bedrock Valley. Locally the Mahomet Sand is underlain by silt, sand, diamicton of pre-glacial origin, and overlain by younger tills of the pre-Illinois Episode. The unconsolidated sediments overlie Pennsylvanian-age shale, siltstone and sandstone of the Tradewater Group (Fig.2.2).

The P-wave seismic reflection technique was able to penetrate deep enough into the bedrock to map the contact with the underlying Mississippian-age rocks.

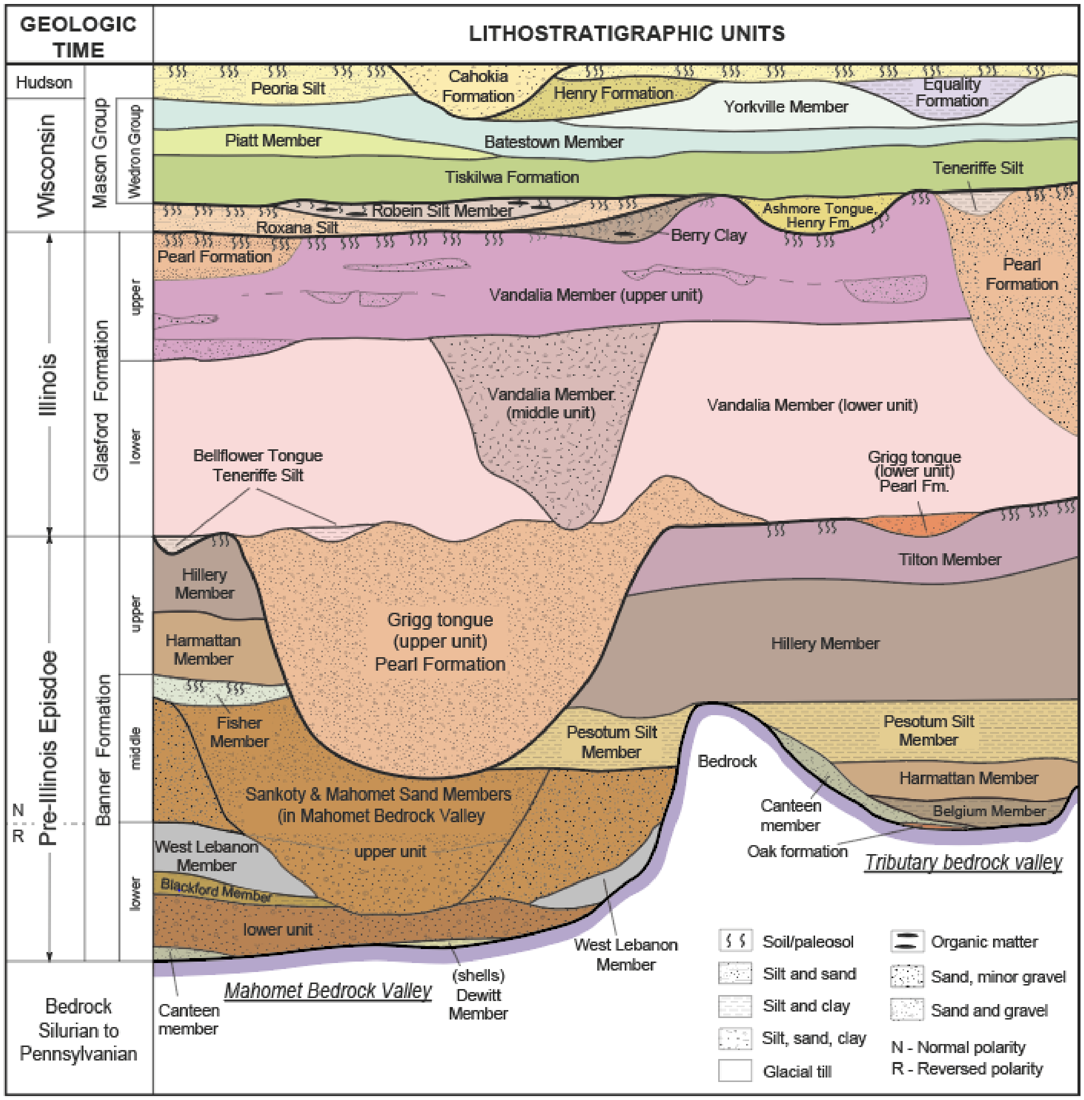

Figure 2.2. Diagrammatic stratigraphic column of glacial and non-glacial sediments in east-central Illinois (Revised from Kempton et al., 1991)

CHAPTER III

METHODOLOGY AND DATA ANALYSIS

A team from Illinois State Geological Survey (ISGS) acquired the study data. The seismic data were donated to us as shot gathers to analyze and use for this study. The seismic data consisted of a series of high-resolution P-wave seismic reflection profiles totally approximately 13 kilometers. In addition to the seismic data, vertical seismic profile (VSP) containing both the compressional (P) and shear (S) wave velocities logs collected from one shallow bore located along seismic profile 717 as well as a series of gamma ray logs and lithological description logs of boreholes in the study area were obtained.

According to Vereecken et al. (2005) acoustic waves generated by seismic sources at the surface or in boreholes propagate downward to encounter geologic interfaces demarcating discrete geologic units owing to impedance contrast between these units. Part of the propagating wave is reflected at the interface while part is transmitted into the underlain strata. Ramsayer (1979) outlined this principle stating that primary seismic reflectors are generated at physical surfaces having a velocity and/or density contrast.

Valuable information derived from seismic methods are wave velocities, amplitude and wave attenuation, from these quantities, other vital information about the aquifer and its material make up can be derived such as aquifer thickness, distribution, strata sequence, porosity, water saturation, etc.

The obtained seismic data were acquired using the P-wave land streamer technology developed by ISGS (Pugin et al., 2006), where 50 lbs. weight drop was used as an energy source and 36 geophones mounted on metal sleds and spaced at 2 m intervals were used as receivers. The survey and acquisition parameters of the data are shown in Table 1. The land streamer data were acquired along low traffics and flat paved roads and exhibited relatively good quality (Fig. 3.1).

Table 1: Survey and recording parameters of the P-wave seismic profiles.

Recording channels	36
Geophone interval	2 m
Nominal offset	2 m
Shot interval	2 m
Number of stack	1-3
Geophone type	Vertical 100 Hz
Source	50 lbs. weight dropper
Sampling rate	0.25 ms
Record length	0.5 seconds
Filters	10 Hz and 500 Hz
Recording system	Geode
Positioning system	Trimble DSM212H

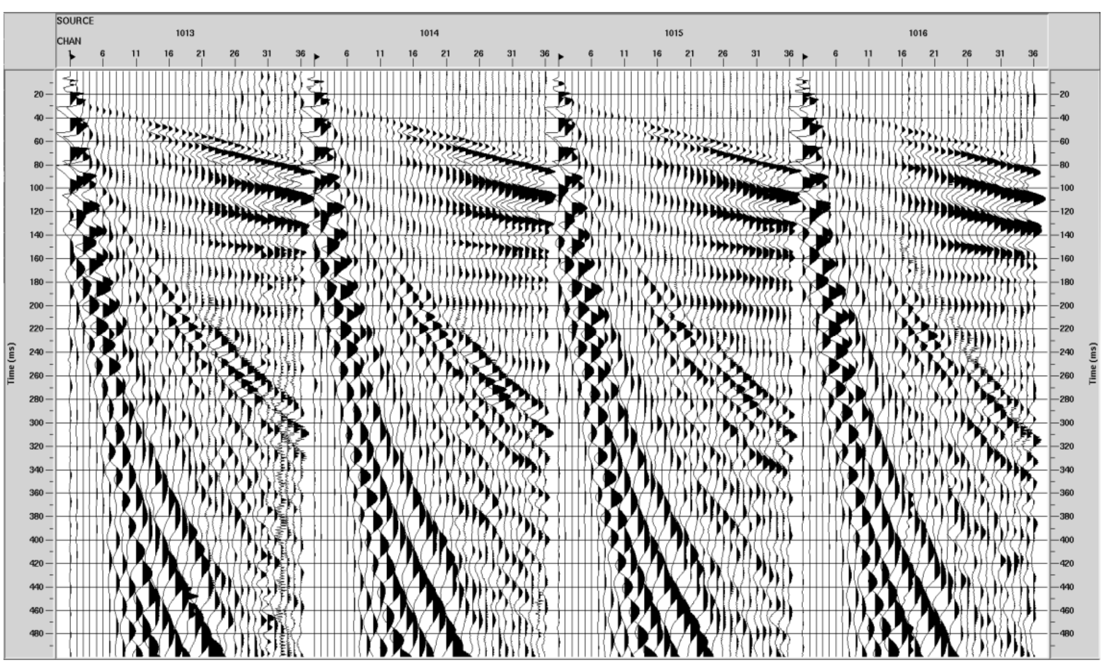

Figure 3. 1: Examples of raw shot gathers acquired by the P-wave land streamer at the study area.

The acquired seismic data, in its raw state is meaningless, and must be transformed to obtain high resolution images representative of the study area subsurface geology through data processing. The SeisSpace ProMax Seismic Processing Software was used for data processing at the Geophysics Lab of Boone Pickens School of Geology, Oklahoma State University. For optimum results, processing was aimed at improving the signal to noise ratio, enhance signal resolution and limit or avoid the introduction of processing artifacts. Figure 3.2 illustrates the processing workflow applied to the recorded seismic wavefield.

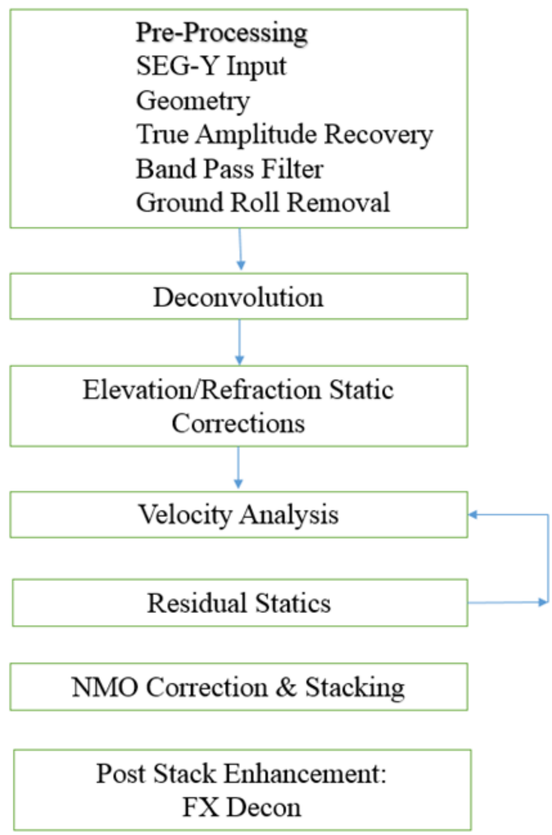

Figure 3. 2: Applied processing workflow

Thereafter, satisfactory processed stacks were incorporated into Kingdom interpretation software. Data interpretation entails assigning geologic significance to events observed on the processed stacks. As a first step, we used gamma ray logs derived from evenly spaced wells located along seismic profile 717 to construct a geologic cross-section. The section is a two-dimensional slice of the subsurface employed to infer and or understand the geologic conditions that occur in specific areas of the cross section. This also provided a visual representation of the geology of the study area showing the distribution and thickness of the mapping units present and how they relate to one another. Next, reflectors on the processed seismic stacks were picked and correlated to wells located along or within the vicinity of seismic profiles. Finally, the reflectors were assigned to discrete geophysical units based partly on geologic logs available along the survey lines and the variation in nature of seismic reflections.

At rural western Champaign County, the series of seismic profiles, approximately 13 km in total length, received in SEG-Y format was transferred to ProMax Seisspace for processing and analysis. Thereafter, as a first step in data processing, correct definition of acquisition geometry using the 2D Land Geometry Spreadsheet created the ProMax Database Files and loaded header information into the trace headers. Promax uses the database to sort the traces and perform subsequent processing functions. Seismically, imaging depths shallower than 200 m is complicated owing to the mixing of primary reflections and surface waves (Francese et at., 2007). The recorded seismic data exhibited ringing refractions and strong coherent surface wave noise such as, spatially aliased broadband high-frequency air coupled waves and ground roll (Fig. 3.3a). Though the quality of the shot gathers appears reasonably good, these events affected their overall quality vis-a-vis the stacks, thereby complicating data processing. At the study area, high amplitude, low frequency and very low velocities represents the ground roll, computed phase velocity ranges from about 200-250 m/sec, and it appears non-dispersive suggesting a fairly uniform low velocity soil underlain by a much higher velocity layer. The velocity of the refracted first-arrival is much higher. The ringing refraction is thought to lay in the low-velocity layer above the till. The high amplitude of the coherent noise is related to surface geologic conditions, particularly the lateral and vertical variability of the interval velocities within the upper few meters. VSP data derived from a shallow borehole (CHAM-07-02A) located along the seismic profile 717 confirms an abrupt increase in velocity from about 311m/s at 4m to as high as 1900m/s.

Following the data formatting and geometry assignment, a true amplitude recovery process was applied in order to boost up the later arrivals. Then, a frequency band pass filter of 20/30/220/250 Hz representing the low cut / low pass / high pass / high cut frequencies, respectively was designed and applied based on the spectral analysis of the raw seismic data and estimating noise versus signals frequency bands (Fig. 3.3b). Ground roll tends to mask useful primary reflections and usually occurs when incident P and SV plane waves interacts at the free surface and travel parallel to that surface to be recorded by the geophones. Steeples and Miller (1998) listed source and geophone arrays, frequency filtering, F-K filtering and stacking as classical methods used to eliminate ground roll. To eliminate this noise type from the data set, several advanced noise-filtering techniques such as F-K filter, Surface Wave Attenuation filter, tau-p filter and Ground Roll Attenuation methods were tried, and the results compared. In comparison, as the name implies, the Ground Roll Attenuation method was much more effective in ground roll elimination (Fig. 3.3c). This method, apart from avoiding sampling and smearing issues, is also devoid of irregular trace spacing and spatial aliasing that compromises the effectiveness of F-K filter and tau-p in eliminating ground roll (Landmark Software Manual, 1998). It involves a two-step procedure where 0.3 singular value decomposition (SVD) estimated the ground roll within a localized time-space window, then adaptively subtracted the ground roll from the data in the second step. This technique was effective in attenuating most of the ground roll and associated aliasing without the introduction of unwanted artifacts into the data, (Fig. 3.3c).

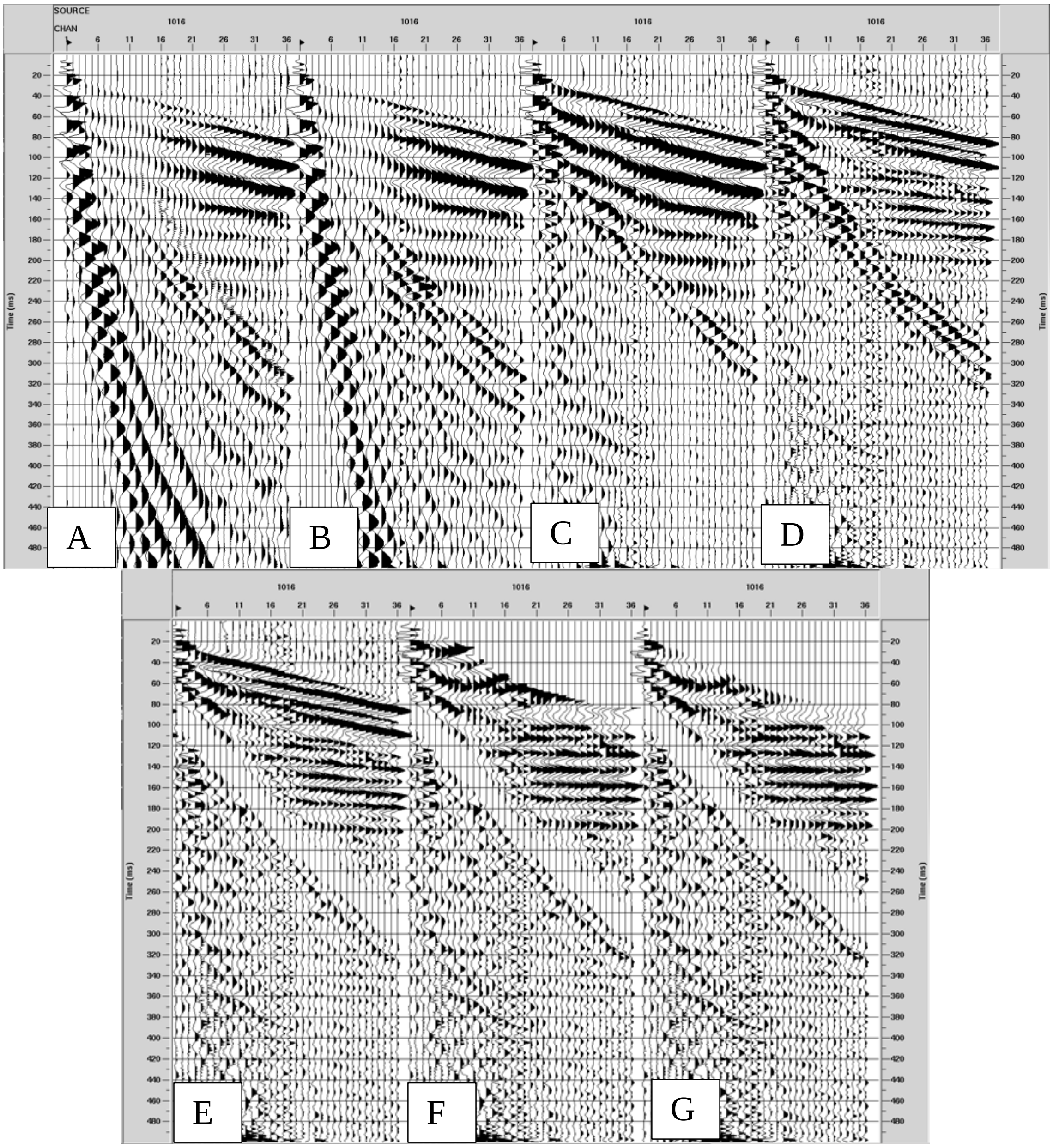

Figure 3. 3. Seismic shot gather with the main processing steps applied: (A) raw shot gather, (B) frequency filtering, (C) ground roll removal and (D) after deconvolution. (E) Air-coupled waves eliminated, (F) NMO correction, and (G) mute function.

Predictive deconvolution was applied primarily to increase temporal resolution and also to suppress periodicity such as multiples if any (Yilmaz, 1987). Zhou (2014) defined deconvolution as a direct application of inverse filtering to “undo” a convolution. The recorded signal is a convolution of various elements including the geophones and the earths response, resolving the signal into constituent parts will collapses the wavelet into a spike thereby improving temporal resolution. The reflections as shown in figure 3.3d could make for more positive identification through their pronounced hyperbolic movement after the application of deconvolution. Because deconvolution can be very involving, running amplitude spectral analysis of the trace data before and after deconvolution is a sure way of deciding if parameters used for deconvolution worked. Flattening or whitening of the spectrum after deconvolution relative to before showed the deconvolution parameters we used worked properly.

Interpreting air waves and air-coupled waves as actual seismic waves is one of several pitfalls to avoid in shallow seismic reflection surveys, (Steeples and Miller, 1998). With our data, prior to its proper attenuation, the air-coupled waves posed enormous challenge especially during the velocity analysis process. Owing to spatial aliasing of air-coupled waves, Steeples and Miller (1998) urged caution in the use of F-K filtering to avoid enhancing components of the air-coupled wave that could stack coherently on CMP sections. Additionally, in most cases and as with our data, air coupled waves last several cycles which causes a portion of the high frequency wave to fall outside the mute in F-K space. These parts of the airwave that fall outside the mute may stack coherently at velocities that are reasonable for near-surface materials. Though we attempted several advanced filtering methods but none worked and surgical mute was most effective in its removal (Fig.3.3e). The air-coupled wave is characterized by high amplitude, high frequency, low velocity ranging from 320-340m/s and is spatially aliased.

Statics corrections are necessary to compensate for the time distortions of topography and time delays from near-surface geologically weathered layers with variable low velocities, (Liu et al., 2005). This is even more so given that within the near surface, reflected events are generally less continuous and their high frequency in relation to statics shift can be detrimental to stacking (Schmitt, 1999). Thus, to account for incorrect time shifts that may have resulted from topography of the survey site, we computed and applied accurate elevation statics using 230m floating datum. However, no appreciable difference was observed between stacks with elevation statics correction applied and stacks without elevation statics applied, as the computed statics are very negligible. A plausible explanation for this could be the fact that the survey was conducted along relatively flat roads in rural western Champaign County. The relative flatness of the roads could not have induced considerable time shift into the recorded seismic to warrant elevation statics correction. For refraction statics, the Neutral Network First Break Picking facilitated careful picking of first break arrival on all traces of each shot gather and with an alternative option “use V_0 but compute uphole times” in the Promax Refraction Statics Calculation module, repeated iteration varying the V_0 and replacement velocity values yielded good statics solutions of both 1 and 2 layer models. The statics solutions show good correlation between the source and receiver statics. The calculated refraction statics correction was then applied using the “Apply Refraction Statics” module, however, on application especially on Profile 720, while not substantially improving the shallow part of the stack, the deeper reflections around 160 ms were degraded though minutely. Eventually, we conclude that either the total acquisition spread length of 72 m is limited to allow for correct refraction statics calculation or that the study area is without major statics challenges to warrant statics corrections.

The ProMax velocity analysis tool is used to pick the velocities for velocity analysis calculation. The derived velocity field is then used for NMO correction (Fig.3.3f) on the data and to obtain a stacked section suitable for interpretation (Fig. 3.5). A supergather was formed using Promax 2D Supergather Formation module by combining 5 CDP’s generated at regular interval, at increment of 11 CDP’s along each survey line. The CDP increment of 11 represents good regular sampling interval of the data along each seismic profile and sample any lateral velocity variation (3.4).

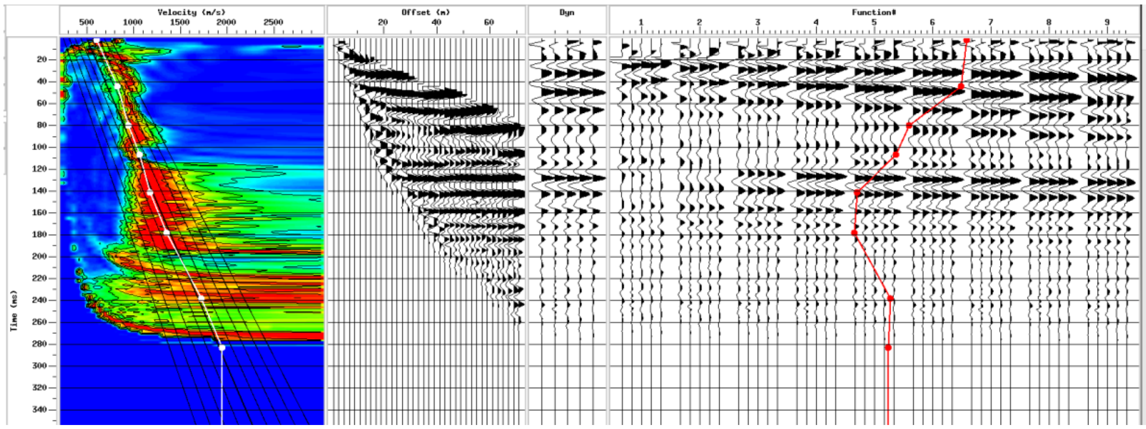

Figure 3. 4. Velocity analysis of processed seismic data with the velocity semblance (left panel), the seismic super gather (middle panel) and stacks at fixed velocity functions (right panel).

Following the velocity analysis, the CDP gathers were moved out and stacked. Stacking is very fundamental to seismic data processing and involves the summation of all traces belonging to a particular CDP. Through CMP stacking using the velocity field derived from velocity analysis we obtain the first available interpretable images of the subsurface (Fig. 3.5a). To further clean up and optimize the stack, additional poststack signal enhancement processing was thought necessary. Thus both F-X Decon and Dynamic S/N filtering were tested, F-X Decon was chosen in preference to Dynamic S/N filtering. F-X Decon is designed to attenuate random noise and unlike the Dynamic S/N filtering there is no little mixing or lateral smearing of data. Thus we applied the Wiener Levinson type of F-X Decon with 300 Hz as maximum F-X filter end frequency yielding the optimum stack, figure (Fig. 3.5b) shows the result thereafter.

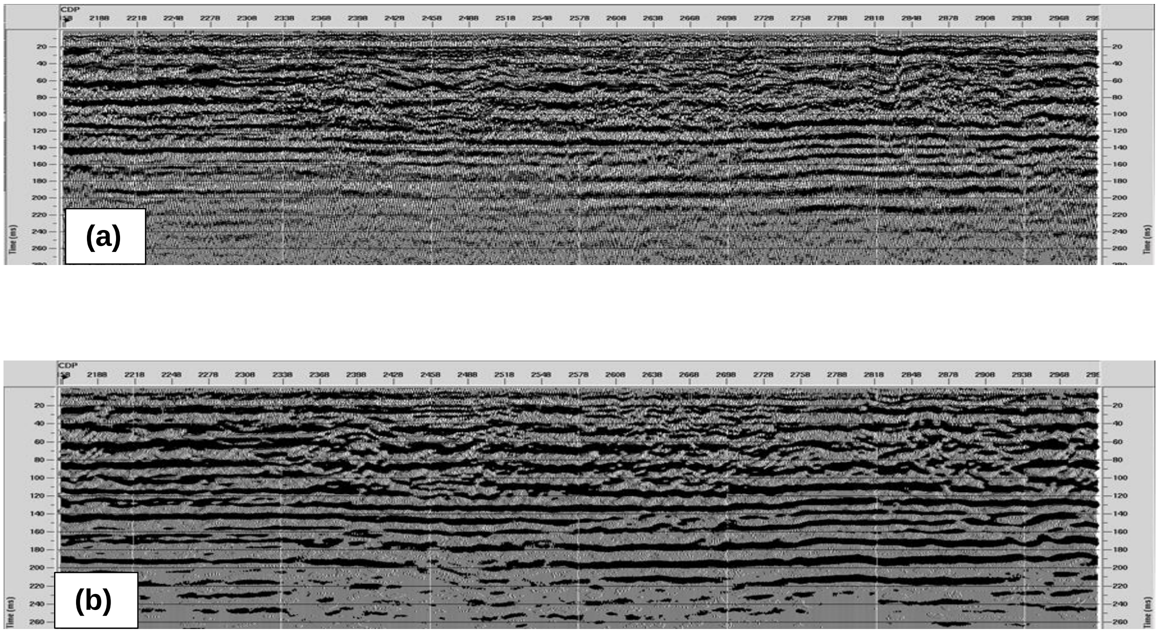

Figure 3. 4: (a) Stacked time profile generated from vertically CDP stacking using the velocity analysis field derived from the velocity analysis process and (b) the same stacked section after applying F-X decon.

CHAPTER IV

RESULTS & INTERPRETATION

The processed seismic lines of 13 Kilometers in total length were interpreted to characterize Aquifer system in the study area. The interpretation process started by building a geologic outline of the surveyed area based on available borehole lithological descriptions and well logs. This helped to understand the lateral and spatial variations in the area and enabled tracking of the continuity of depositional layers. This was followed by seismic to well log correlations in order to tie the major seismic horizons with corresponding lithological variations and assign the seismic reflections to corresponding lithology. This was used to interpret the seismic lines into different lithological layers. The three steps of the seismic interpretation workflow are described below.

4.1 Well Logs Correlation

Gamma ray logs derived from wells located along and within the vicinity of seismic Profile 717 helped to construct a geologic cross section that reveals the sequence of geologic units encountered in the study area, (Fig. 4.1). The constructed section is a two-dimensional slice of the subsurface employed to infer and or understand the geologic conditions that occur in specific areas of the cross section. This also provided a visual representation of the geology of the study area showing the distribution and thickness of the mapping units present and how they relate to one another. The cross section was built from west to east, G-G′along seismic Profile 717; the where wells located along this profile have a good spread. Well LW #69 is located about 725 m from well LW 71 while well TH-1-07-68 is located 1.2 km farther from LW #69. None of the gamma ray log is thought to have penetrated the bedrock. In unconsolidated sediments, relatively low natural gamma count is indicative of porous and permeable coarse-grained sediments (sand and gravel), in contrast to relatively high natural gamma count that is indicative of clay-rich sediments (till, silt or clay). From the cross-section, Pennsylvanian-aged bedrock underlain Quaternary glacial and non-glacial deposits grouped into four major litho-stratigraphic units: Banner Formation, Pearl Formation, Glasford Formation and Tiskilwa Formation. These formations were deposited during various glacial episodes and intervening periods and also consists of various interstratified subunits.

The Pennsylvanian-aged bedrock is unconformably overlain by coarse to medium sand and gravel assigned to the lower unit of Mahomet Sand Member of the Banner Formation, partly based on relatively low gamma ray counts. The thickness varies across the profile ranging from 10-17 m. Relatively thick coarse upward fining sand and gravel overlies the lower unit of Mahomet Sand Member, Banner Formation. This unit is thicker at the eastern flank of the profile and has a relatively low gamma reading though higher than the values of the underlain lower unit. The Banner Formation is overlain by laterally extensive fine to medium sand assigned to the Grigg tongue 2, Pearl Formation. This unit is uniformly thick in wells LW #69, TH-1-07-68, LW 71 but much thicker in CHAM-07-02A and is encountered from about 61m depth. The Pearl Formation is an outwash deposited during the Illinois glacial episode. Deposits of the Grigg tongue 2 is overlain by variably thick sections of the Glasford Formation. The lower Vandalia Member of Glasford consist of hard gray clay with gravel, and shows relatively higher gamma values compared to the underlain units. The lower Vandalia is conspicuously absent in well BW Well 68 (Fig. 4.1) as channel deposits directly overlie deposits of the Pearl Formation encountered in this well. Fine sand and also clay with sand and gravel (till) with some cobble, both of the middle

Vandalia Member are found in this well, and the later extensively thick. These units' deposits are absent in wells LW 71 and LE #69.

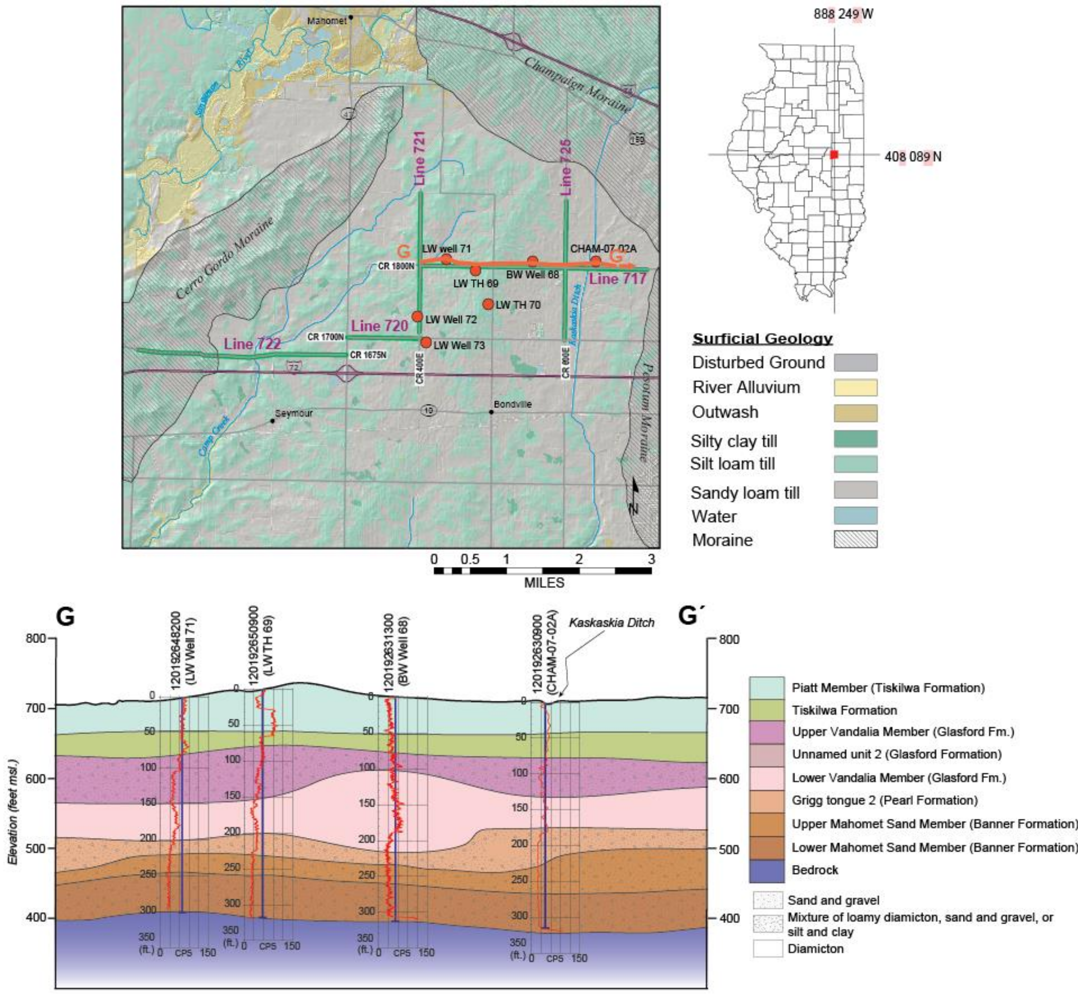

Figure 4.1: A geologic cross-section G – G' in the study area from east to west paralleling seismic Profile 717.

Because the middle unit of Vandalia Member (channel deposits) is absent in wells LW 71 and LW #69, the upper unit of Vandalia Member overlain the lower unit. While in well TH-1-07-68 upper unit of Vandalia directly overlies the middle unit of Vandalia member. The absence of some units indicates that the geology and hydrogeologic units vary laterally across the profile. Vandalia Member (upper unit) consist of several interstratified intervals of variable thick deposits: fine to medium sand and gravel overlain by thick gray clay with gravel interval, both of this units show relatively low gamma values while the overlain fine to medium sand and gravel, brown clay with gravel shows medium to high gamma ray readings. The Glasford Formation units were deposited during the Illinois glacial episode.

The Tiskilwa Formation which can be encountered at 14 m depth overlies the Vandalia Member (upper unit) of Glasford Formation. This unit varies from gray and brown clay with gravel, diamicton, till with some cobbles across the profile and shows a relatively medium to high gamma ray readings, the thickness is about 7m at the flacks and less at the middle of the cross section. The Piatt Member, Tiskilwa Formation was the last unit to be deposited during the Wisconsin glacial episode. This unit consist of brown clay and black topsoil, which overlies gray clay with gravel, together both subunits ranges from about 14m at the flanks though thicker at the middle cross section and show high gamma ray readings.

4.2 Seismic-Well Log Correlation:

High-resolution seismic reflection surveys are usually undertaken as part of an integrated research effort where other data types are acquired to aid and facilitate seismic interpretation. Without the collaborative aid of these other data types, characterizing glacial deposits using HRSR data by itself will be an exercise in futility owing to the complexities associated with these deposits. Figure 4.2 illustrates a part of seismic profile 720 correlated to the lithologic description and the gamma ray log of well LW 73 located along the seismic line. The seismic line, reveals several interfaces from about 205 m – 120 m depth.

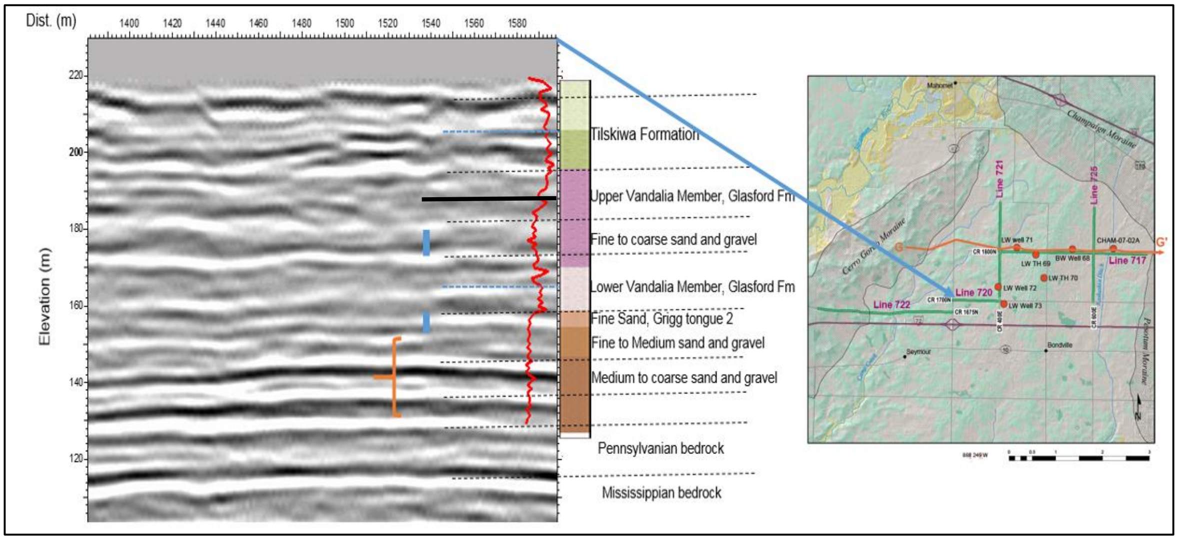

Figure 4.2. Seismic well log correlation, part of seismic line 721 correlated to logs from well LW 73

At about 124 m, lies a laterally continuous very strong reflector, though well LW 73 did not penetrate to this depth, this reflector is interpreted as the interface that separates the underlying bedrock deposits and deposits of the overlain Banner Formation. At 130 m lies another laterally continuous and very strong reflector. Hitherto, the lower unit of the Mahomet Sand Member from about 140 m – 124 m was described as a unit. However, the presence of an obvious seismic interface at 130 m splits the lower unit of the Mahomet Sand Member into two subunits. Approximately at 140 m lies a reflector that correspond to the top of the lower unit of Mahomet Sand Member. The lower unit of the Mahomet Sand Member consists of medium to coarse sand and gravel and is about 16-20 meters thick, together with the unaccounted middle unit. The reflector at 153 m corresponds to the top of the upper unit of the Mahomet Sand Member which consists of fine to coarse sand with gravel. Thus, the subunits (lower unit/upper unit or lower unit/middle unit/upper unit) from approximately 153 m – 124 m constitute deposits of the Banner Formation and represent the Mahomet Aquifer, the principal aquifer within the Mahomet Aquifer System. Generally, deposits of the Banner Formation tend to fine upward and down valley from east to west.

The position of the reflector at about 157 m in the form of shallow channel correlates well with gamma log derived from Well-LW 73 to be the top of Grigg tongue 2, Pearl Formation. This unit consists of fine to medium sand and is about 10-14 m thick. Despite its fine sand constituent, this unit can also be considered an aquifer and there may exist some degree of interconnectivity between this unit and the underlain prolific deposits of the Banner Formation, since there exist less encumbering unit lying in between both units to prevent downward infiltration of water. The gamma spike marking the top of the lower Vandalia Member correlates with the reflector at 170 m, the deposits lying in between 170 m and 164 m has been described as hard gray clay with gravel. Generally, this unit is fairly uniformly thick about 14 m and serves as a confining layer to the underlain Grigg tongue 2 aquifer. Based on its clay content and thickness will restrict/impede downward infiltration of water. Gamma and its description indicates the presence of thin unit of interstratified sand and gravel at 174 m close to the base of the upper unit of the Vandalia Member directly overlying gray clay to hard gray clay with gravel at the base. The gamma log and litho-description described Vandalia Member, upper unit as a thick whole unit, from immediately above these interstratified subunits. However, the seismic section and gamma ray log both suggest that there may be another subunit within the upper unit of the Vandalia Member that are noticeably missing from the litho-description. At about 180 m and 190 m exists an obvious spike in gamma indicating lithologic change. The spike indicated in black correlated well with a seismic reflector as shown in figure 4.2. Based on litho-description, the upper Vandalia Member consists of brown to gray clay with gravel. At about 205 m and 197 m exist two other reflectors with the deposits in between described as gray clay with gravel and noted as part of the Piatt Member. Though these deposits may contain pores to hold water, the lack of interconnectivity between the pores eliminates such deposits from being considered as aquifer.

4.3 Seismic Profiles Interpretation

Correlations between well logs and seismic profiles has helped in assigning the seismic interfaces into corresponding lithological changes. Accordingly, eight to nine seismic units have been identified along the seismic lines. These units include, from bottom to top, bedrock with top surface marked by a prominent seismic interface located at a ground elevation of 125 m (Fig. 4.3). The bedrock surface representing the most prominent and laterally coherent reflector along the various seismic profiles, (Figs. 4.3-4.6). Recent studies have determined that the extent and thickness of the Mahomet aquifer is even more variable than previously thought, because the bedrock surface contains numerous undulations and isolated structurally controlled protrusions, which together reduce the aquifer thickness. However, in the study area, seismic profiles reveal the bedrock surface is relatively flat with obvious few gentle undulations.

Although vertical seismic velocities were not measured in the bedrock because the boreholes were either not open below the bedrock surface or drilling did not penetrate deep enough into the bedrock to allow borehole geophysical logging. The profiles from the survey do show seismic stacking velocities almost twice those measured in the overlain deposits. The bedrock is composed of two units; the Pennsylvanian-aged strata underlain by Mississippian and older rocks, (Figs. 4.3 – 4.6).

Because Pennsylvanian-aged rocks are eroded by glacial meltwater in some places, the Mississippian and older rocks subcrop as the bedrock surface as can be seen along the western two-thirds of seismic profile 722 (Fig. 4.4). Along this profile, a thin strip of the Pennsylvanian-aged upper bedrock pinches out on the surface on the Mississippian-aged bedrock.

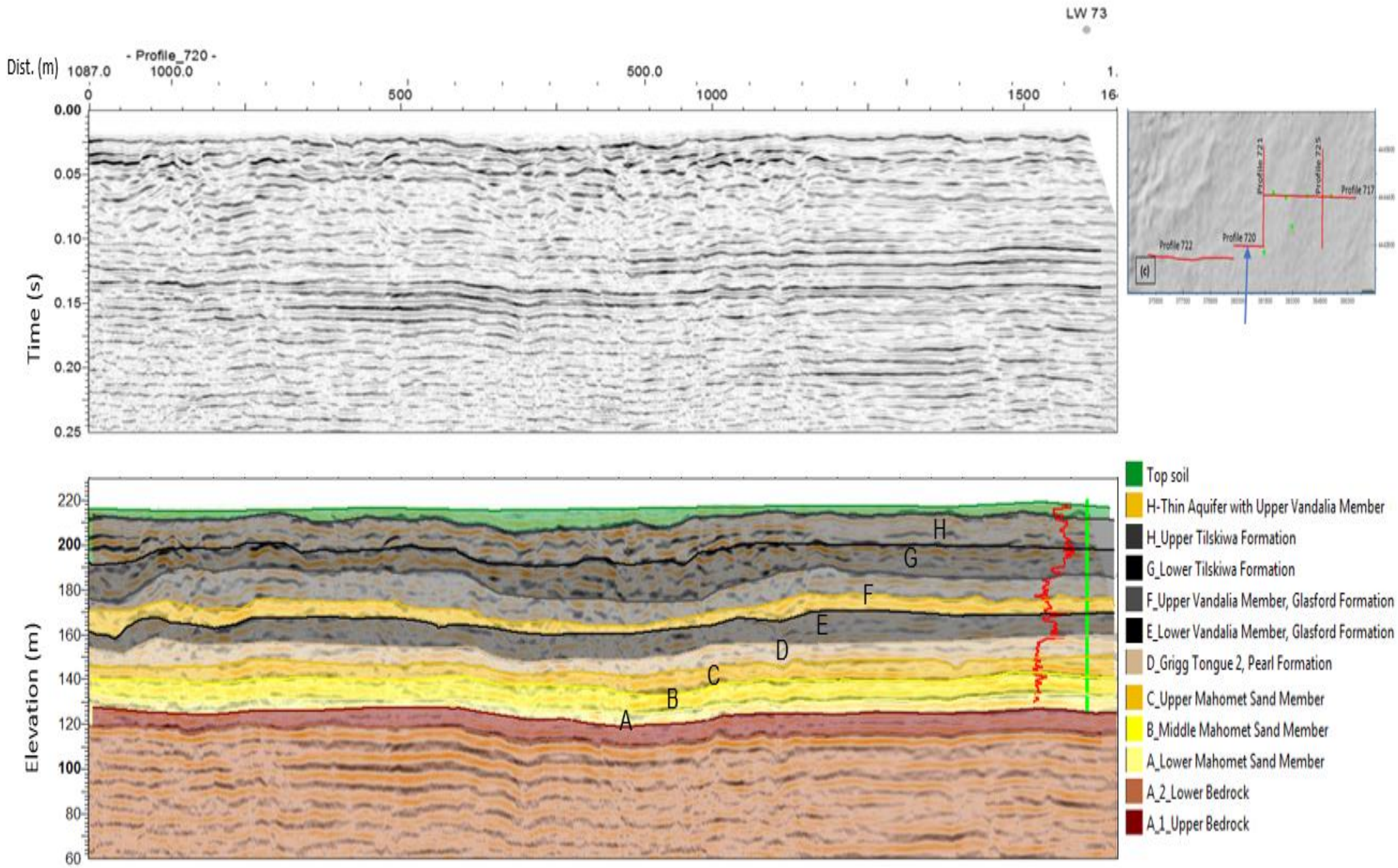

Figure 4.3. Seismic Profile 720 showing (a) time section and (b) seismic interpretation of the depth section

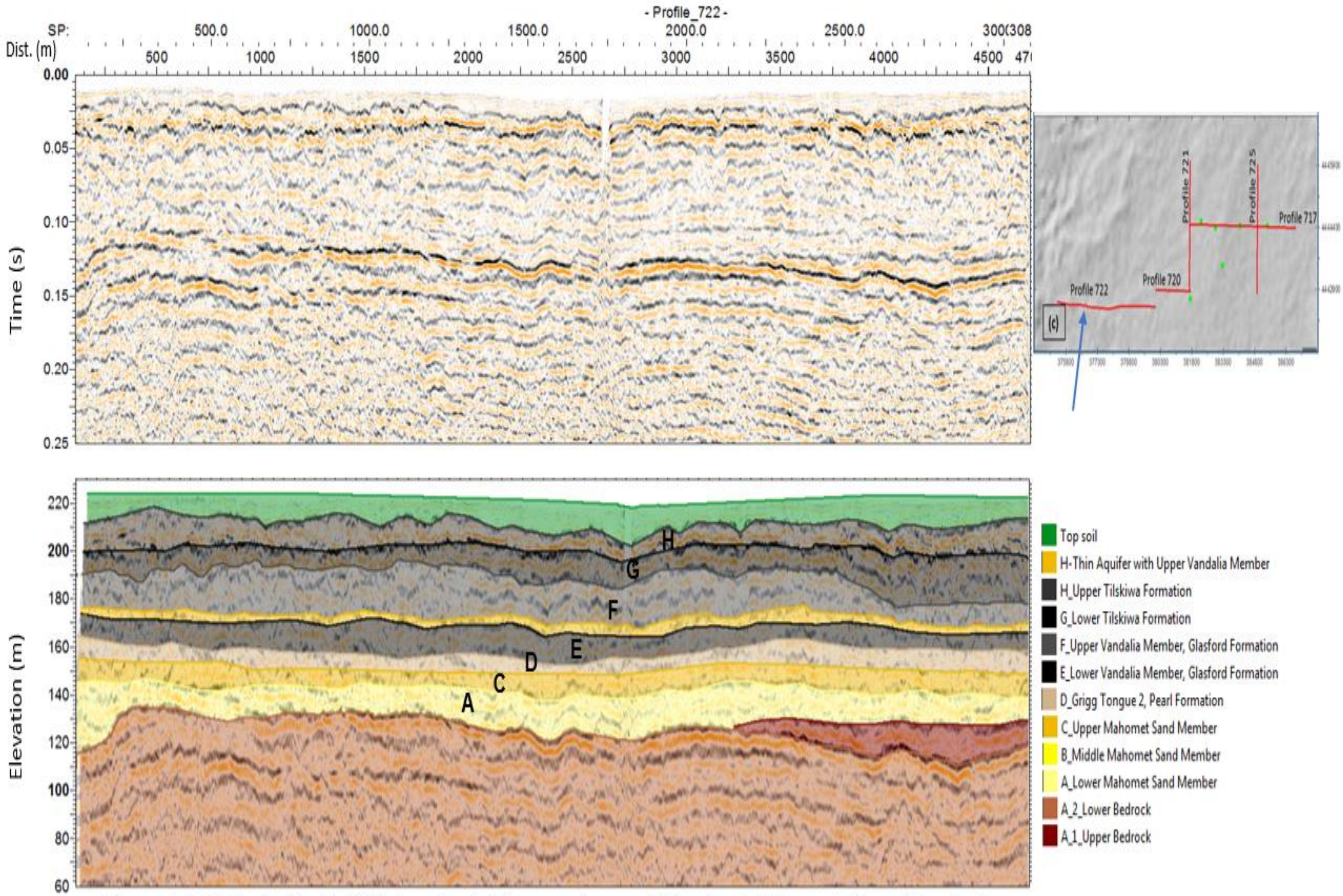

Figure 4.4. Seismic Profile 722 showing (a) time section and (b) seismic interpretation of the depth section.

The bedrock is overlain by various units of glacial and non-glacial materials deposited during the Quaternary Period and consist of four major litho-stratigraphic units. Prominent seismic profiles produced within the deposits are labelled alphabetically from A-H on the seismic reflection line (Figs. 4.3-4.6). Assigning these reflectors to discrete geophysical (seismic) units was based partially on the geological information, geophysical data collected from boreholes along and within the vicinity of seismic survey lines and variations in nature of the seismic reflections.

Seismic Unit A is interpreted as the lower Mahomet Sand Member directly overlie the upper bedrock surface except where the upper bedrock has been eroded (Fig. 4.4). This unit composed of clean coarse sand and gravel is overlain by seismic unit B. Some previous studies had interpreted units A and B as a single unit, Lower Mahomet Sand Member. However, following on from seismic and well log correlation, we interpreted the lower unit to include the middle and lower units of the Mahomet Sand Member. This interpretation agrees with Soller et al. (1999) suggestion that the Banner Formation consists of three units: upper, middle and lower units. The reflectors demarcating these units form a saucer-like shape in the middle of seismic profile 720, though laterally continuous but are also discontinuous at places, chaotic and difficult to trace across the entire section of the seismic profiles. Seismic unit B is composed of medium sand and gravel and overlain by seismic unit C. Together, these seismic units form the Mahomet Aquifer with an average thickness of about 35 m and are composed of clean coarse sand to fine sand with gravel-the upper unit and medium to coarse sand and gravel, middle to lower Mahomet Sand Member. The top of seismic unit C is poorly delineated along most of the seismic lines because of lack of significant contrast in seismic velocity between these deposits of sand and gravel that are commonly water-saturated and underlying finer-textured materials. However, where delineated, the upper contact of seismic unit B ranges in depth from 150 m -175 m.

Seismic unit D is composed of fine to medium sand assigned to Grigg tongue 2, Pearl Formation. The top reflector demarcating this unit from the overlain unit is not laterally continuous and difficult to trace along the entire offsets. Deposits of seismic unit D can be encountered from about 175 m below ground surface and appears to dip southwards across the profile with a fairly uniform thickness of about 10 m. Seismic unit D is an outwash deposited during the Illinois glacial episode.

Seismic Unit E is assigned to the lower Vandalia Member while unit F is of the upper Vandalia Member of the Glasford Formation. The wavy and seemingly laterally continuous reflector at about 203 m (Fig. 4.4) marks the top of the Glasford Formation. The other reflectors within this formation appears wavy, discontinuous and follow the overall southward dip of the seismic profile. Seismic unit F assigned to the upper Vandalia Member overlies unit E. At the base of seismic unit F lies a relatively thin laterally continuous unit composed of sand and gravel. Along seismic profile 717 (Fig. 4.5), the upper unit also contains a channel filled with multi-layered deposit. This agrees with the geologic cross section in figure 4.1. From a few boreholes drilled over these features, the geological and natural gamma radiation data collected suggest the valley or channel(s) are filled with deposits diamicton, silt, and clay and gravel. This incision occurred when meltwater of glaciers eroded into older glacial and non-glacial sediments. The valley or channels may have occurred along all the survey lines from about 180 m.

Seismic Units G and H have a thickness of about 26-29 m and is subdivided into two units corresponding to Batestown Member and overlain Piatt Member, both of Tiskilwa Formation. This unit has a wavy and seemingly laterally continuous strong and coherent basal reflector and a weak reflector present in the middle unit that corresponds to the contact between the Batestown and Piatt Members of the Tiskilwa Formation. Both units are containing materials that are predominantly diamicton: clay with gravel assigned to the Batestown Member, gray clay with gravel and topsoil both assigned to the Piatt Member. The seismic profiles were not able to resolve aquifer(s) within these units.

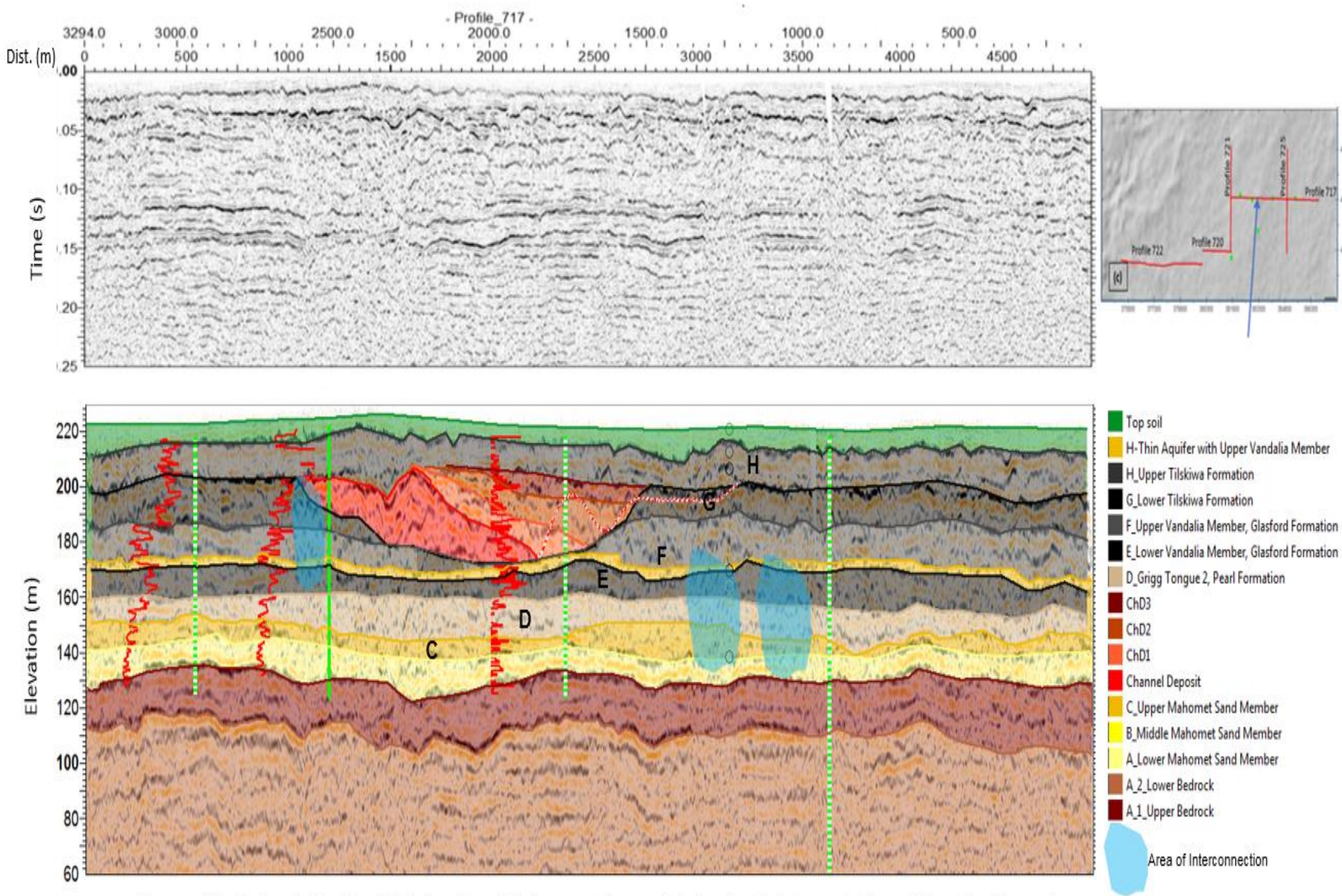

Figure 4.5. Seismic Profile 717 showing (a) time section and (b) seismic interpretation of the depth section

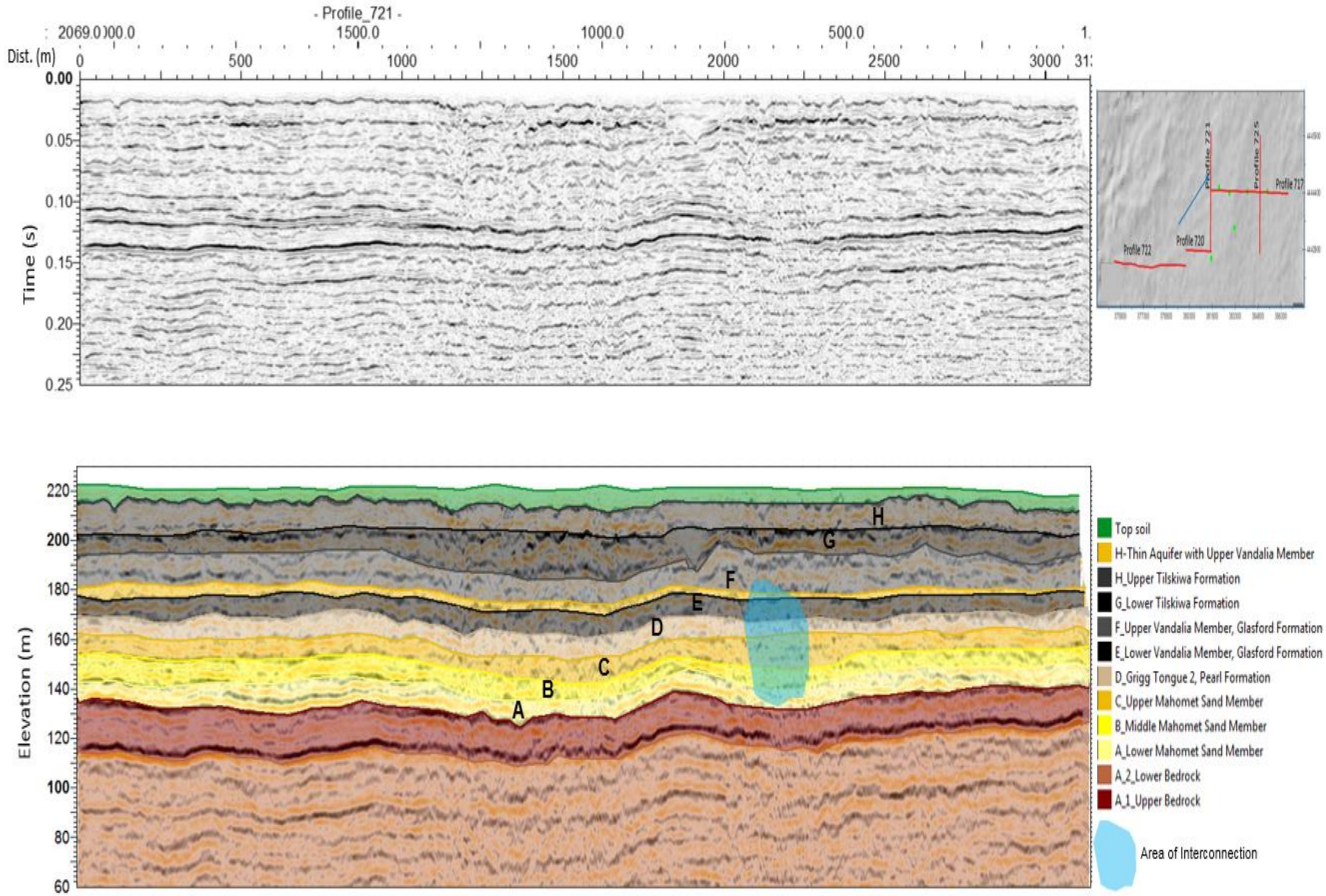

Figure 4.6. Seismic Profile 721 showing (a) time section and (b) seismic interpretation of the depth section

CHAPTER V

DISCUSSION

The processed and interpreted seismic profiles imaged the bedrock surface in the study area, which dominantly Pennsylvanian Shale changing to Mississippian-Dolomite in the western part. The bedrock surface occurs at depths ranging from 100 to 120m. Imaging depths to bedrock as well as bedrock topography and lithological variation is fundamental because the bedrock topography controls the thickness of the overlying drift that form the groundwater aquifers (Krothe and Kempton, 1988). Herzog et al., (1995) and Mehnert et al., (1990) noted that the geometry and geology of the Mahomet aquifer is even more complex than previously thought because the bedrock surface exhibit several small hills that reduces the aquifer unit thicknesses. In the study area, though are some small bedrock surface undulations that slightly affect the thickness of the overlying aquifer units. The lateral variation in the bedrock from shale to dolomite is expected to affect the groundwater chemistry locally.

Two units of the Banner Formation assigned to the lower and upper Mahomet Sand Members overlie the bedrock surface. These units are laterally extensive and reasonably thick (35-40m) and based on seismic-to-well log correlation, they are composed primarily of clean sand and gravel that tend to fine upward and down valley (east to west). Based on seismic well log correlation, we have raised the possibility of the existence of middle Mahomet Sand Member along seismic profile 720

Lithologic description associated with gamma did not account for this unit. However, an earlier work by Soller et al. (1999) supports our hypothesis as there are actually three units making up the Banner Formation Units of the Banner Formation are sandwiched within the Mahomet Bedrock Valley, which is buried by thick glacial and non-glacial deposits. The Banner Formation was deposited by associated melt water flowing away in front of advancing ice during the pre-Illinois glaciation. The associated melt water eroded part of the bedrock lithology, incorporated the material into the overlain glacial drift deposits thereby changing the drift lithic characteristics. In places, the Banner Formation uncomfortably overlies the lower-Mississippian-aged bedrock because the upper-Pennsylvanian-aged bedrock was completely eroded as seen in seismic profile 722 where a thin strip of the upper bedrock pinches out on the surface of the lower bedrock.

It's been continually albeit erroneously stated that the Mahomet aquifer is recharged by rain that infiltrates through the soil. The validity of this hypothesis is questioned, given the existence of thick hydrogeologic barriers that overlie the Mahomet aquifer. Mehnert et al., (2004) offered a more plausible theory, "a hydraulic window connecting the Mahomet aquifer to the Sangamon River was identified in the glacial materials overlying the Mahomet aquifer. This connection allows Mahomet aquifer water to discharge to the river under normal conditions, but allows the Sangamon River to recharge the aquifer when the river is high or when the aquifer is pumped.

A confined aquifer assigned to the Grigg tongue 2 of Pearl Formation overlies the Mahomet aquifer. This aquifer is also laterally extensive, relatively thick and composed of fine-medium sand and can constitute local water sources where available. If the assumption that the Mahomet aquifer is recharged through a hydraulic window connected to the Sangamon River is valid, then the possibility that Grigg tongue 2 of Pearl Formation aquifer is recharged mainly by the Mahomet aquifer through the process of upwelling. The strong P-wave seismic amplitude that marks the top of the Grigg tongue 2 of Pearl Formation aquifer suggests that this unit aquifer is fully saturated. Mavko and Nur, (1979) and Korneet et al. (2004) have experimentally proven that the amplitude of P-wave travelling through water saturated layer is normally higher than the amplitude of the same P-wave travelling through unsaturated layer.

In addition to the three-aquifer units forming the principle Mahomet Aquifer and the overlying fourth unit aquifer of Grigg tongue 2 of Pearl Formation, the lower Vandalia Member of Glasford formation was resolved along most of the seismic profiles as fifth unit aquifer in the system. Though the Tiskilwa Formation is thought to also contain sand and gravel deposits, which serves as aquifers, the seismic interpretation did not resolve this unit. The fife aquifer units within the Mahomet Aquifer System seemed to be interconnected at some locations along some of the seismic profiles. The places where the aquifer units are interconnected might act as hydraulic windows that transport contaminants from the shallower aquifers to the principal aquifers.

CHAPTER VI

CONCLUSION

High-resolution P-wave seismic reflection profiles were conducted over the Mahomet bedrock valley in central Illinois to determine the lateral and vertical distribution of the aquifer units comprising Mahomet Aquifer System and to locate areas of interconnection between various aquifer units. The resolved aquifer units composing the Mahomet Aquifer System within the boundary of the Mahomet Bedrock Valley are the Mahomet Sand Members of Banner, Grigg tongue 2 of Pear and a thin aquifer within the lower Vandalia member of the Glassford Formation. The Mahomet Sand Members of Banner Formation constitute the principal aquifer within the system. It is composed mainly of clean coarse sand, and gravel that fines upward and down valley, laterally extensive and reasonably thick occurring at a depth ranging from 100 to 120 m in the study area. Areas of deteriorated seismic signals are interpreted as windows of interconnection between the main aquifer and the shallower aquifers. The high-resolution P-waves seismic survey clearly imaged the bedrock surface as two units, the upper Pennsylvanian-aged bedrock overlying the lower Mississippian-aged bedrock. Given the inherent subsurface properties of the glacial deposits, the complexity of the geologic setting and the depth of the principal target, high resolution P-wave seismic reflection method aided by the appropriate well-log information is considered efficient in resolving the aquifer units.

Data Management:

The processing data are stored as follows in Promax Seispace processing software:

/data/groups/ahmed_ismail

EAST_CENTRAL_ILLINOIS_ANEKE

The interpretation data is in Kingdom suite under:

Processed stack

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VITA

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Master of Science

Thesis: Seismic Characterization of a Glaciated Multi-Layered Aquifer System in Central Illinois.

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Completed the requirements for the Master of Science in Geophysics/Geology at Oklahoma State University, Stillwater, Oklahoma in May, 20018.

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Experience:
Graduate Research/Teaching Assistant Jan 2017 – Dec. 2017

- ✓ Good experience in geophysical data acquisition, data analysis and interpretation especially 2D seismic.
- ✓ Ability to implement data gathering techniques in a variety of field and water conditions
- ✓ Sound theoretical knowledge in sedimentology/stratigraphy/well logs and analysis and structural geology
- ✓ Proficient in Promax-Seisspace seismic processing software, Petrel, Petral, Oasis Montaj software.
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- ✓ Oklahoma City Geological Society (OCGS)
- ✓ Nigerian Association of Petroleum Explorationist (NAPE)
- ✓ Nigerian Mining and Geological Society (NMGS)